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DATA DYNAMICS, Inc.

305 WEBSTER STREET • MONTEREY, CALIFORNIA • PHONE 375-4133 (AREA CODE 408)

3 November 1965

To: ~~Whitter~~

Dr. Albert D. Wheelon
Deputy Director, Science and Technology
Central Intelligence Agency
2430 E. Street, NW
Washington, D. C.

Dear Bud:

Attached is a resume of our company's activities, with emphasis placed on the work we are doing for Air Force System Command in support of its space activities. Although DDI's forthcoming contract with the Agency to test the value of interaction analysis as an aid to long-range projection of future Soviet weapon systems is not mentioned, I gave full information about it to Ting Sheldon a few weeks ago.

I expect to be in Washington the week of November 15th and will call you then to answer any further questions or to elucidate further on any point of interest. If you are coming West in the near future we would be happy to have you visit Monterey, or Don Criley, the Vice President in charge of our technical staff and I would be pleased to meet with you in Los Angeles.

Sincerely,

Don R. Harris
Vice President

DRH:ll
Encl.

INTRODUCTION TO DATA DYNAMICS, INC.

DDM 149 OCTOBER 1965

Data Dynamics, Inc.
305 Webster Street
Monterey, California

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INTRODUCTION

Data Dynamics, Inc., an independent, privately owned research and development corporation, provides analytical and scientific support to selected government agencies and industrial concerns. The Corporation's principal areas of activity include operations research, systems analysis, simulation, computer programming, data processing, man/machine interactions, and information retrieval.

The history of the staff dates back to 1956 when the nucleus of the present corporation was organized as the Monterey Research Office of Technical Operations, Inc. In 1960, Laboratory for Electronics, Inc., acquired this facility as its Monterey Laboratory Division. This division was purchased from LFE by the present stockholders, and DDI came into being in July 1963.

In addition to the main facility in Monterey, California, DDI maintains other technical staff offices at MacDill Air Force Base and Eglin Air Force Base, Florida. Technical liaison offices are maintained in Palo Alto and Santa Monica, California, Washington, D.C., and Boston, Massachusetts. Each facility is cleared to a level of security appropriate to contractual requirements.

It has been DDI's philosophy to concentrate its knowledge and capabilities in specific areas vital to the nation's military and space programs. This resulted initially in the building of technical capability in depth; subsequently, this focus of capabilities has provided a base for extending into other related areas and has enabled DDI to be active in such diverse programs as operational satellite tracking and limited warfare studies. It has resulted in DDI developing competence in a number of specific areas, including:

- Space science
- Tactical warfare systems and requirements
- Command and control analysis and design
- Field experimentation test and evaluation

- Strategic systems analysis
- Environmental science studies
- Commercial applications.

The nature of our business requires technically competent personnel capable of solving complex problems in specific fields of study and in areas that cut across several disciplines. Functionally, the DDI technical staff is qualified in mathematics, physics, electrical engineering, mechanical engineering, psychology, political sciences, economics, military sciences, astronomy, meteorology, and foreign languages. The extent of the academic qualifications of the DDI staff is evidenced by the fact that all of the professional staff are holders of academic degrees at, or above, the bachelor level; 30 percent are holders of advanced degrees.

Brief descriptions of selected current activities are presented in the following paragraphs.

SPACE SCIENCES

Data Dynamics' experience in aerospace sciences is related to two principal areas: aerospace tracking and orbit determination, and satellite system operations analysis. Of the two, tracking and orbit determination has received the major portion of contractual support. Consequently, it is in this particular technical area that DDI exhibits the greatest degree of competence.

AEROSPACE TRACKING AND ORBIT DETERMINATION

The staff of DDI has been actively engaged, for over four years, in developing tracking programs used in operational support of U.S. Air Force space missions. The activities for which DDI has been responsible include analysis, design and programming of general tracking programs, program evaluation, on-site operational support, operator training, program maintenance, and extensive program adaption. In conducting these activities, extensive experience has been gained in the following areas:

- Satellite ephemeris generation and acquisition prediction
- Precision satellite orbit determination
- Missile trajectory determination
- Data smoothing and editing
- Calibration of tracking instrumentation
- Improved values of physical constants
- Atmospheric drag analysis
- Satellite lifetime prediction
- Optimization of transfer trajectories
- Development and evaluation of operational procedures
- Component failure analysis in spaceborne sensor systems.

Early in 1960, numerous basic system subroutines were developed by the DDI staff for use at the Satellite Test Center under subcontract to Control Data Corporation. In 1961, an orbit determination program based on numerical integration of the Cowell equations of motion was developed and written in 1604 machine language under Aerospace Corporation contract 61-126.

In 1962, DDI designed and developed the orbit determination and ephemeris modules for use in operational support of a complex Air Force satellite program. This work was carried to a highly successful conclusion and has been used operationally since the summer of 1963. Data Dynamics, in the spring of 1963, was again selected to provide orbit determination and ephemeris programs for the operational support of a high-altitude Air Force satellite program. This work was also concluded in the summer of 1963. Later in 1963, DDI was awarded contract AF 04(695)-502 to design and develop the computer programs that would provide the Satellite Test Center with accurate predictions of passive satellites re-entering the earth's atmosphere (tracking impact prediction). In fulfilling these contractual requirements, DDI expanded the capabilities of its tracking program and supported a number of satellite operations with a high degree of precision and accuracy.

At the beginning of 1964, DDI was awarded contract AF 04(695)-573 to expand the orbit determination program to solve for maneuver parameters (thrust, pitch, and yaw). This work was completed six months later.

Currently, Data Dynamics is responsible for developing and maintaining the Orbit/Ephemeris Subsystem for all satellite programs of the Air Force Satellite Control Facility (AFSCF) under contract AF 04(695)-611. The scope of this work is summarized as follows:

- Plan, design, develop, modify, maintain, test, document, evaluate, and provide computer programs associated with orbit determination and ephemeris generation
- Investigate, design, and document advanced orbit determination models, mathematical techniques, and operational procedures
- Provide support and/or training to the Integration Contractor and 6594th Aerospace Test Wing personnel.

The Data Dynamics programming staff, in conducting its work with the AFSCF, has acquired a complete familiarity with AFSCF's operating systems, programming languages, and procedures associated with the software subsystem. In addition, the entire staff has undergone intensive training in the JOVIAL language.

The principal product of this extensive effort is the DDI General Purpose Tracking Program (GPTP) which has provided prime support for numerous satellite missions and is regarded as a calibration standard for other Air Force tracking systems.

The use of the GPTP permits an accurate early-position location of satellites during space missions. Look-angle data generated from the DDI tracking programs is transmitted quickly to tracking radars located throughout the world to obtain early acquisition of the satellite vehicle and further trajectory refinement. Radar track data is first edited and calibrated by the DDI programs; then the programs determine the orbital elements from this data for use in predicting vehicle position and velocity in both local and inertial coordinates. The DDI computer program considers such elements as earth-gravity anomalies, attractions due to sun, moon, planets, aspheric earth with latitude and longitude dependent terms, time variant atmosphere with solar tides, solar flux, planetary magnetic index, and the powered segment of the satellite flight. In addition to the design and programming of the GPTP, DDI has also been responsible for the following:

- Analysis of orbital problems
- Computer program evaluation

- On-site operational support
- Operator training
- Program maintenance
- Extensive program modification and adaption.

GENERAL PURPOSE TRACKING PROGRAM

The DDI General Purpose Tracking Program is an orbit determination and ephemeris prediction system. It was designed primarily to provide support for real-time satellite tracking missions. However, a considerable amount of effort has been devoted to making the program sufficiently general to be of use in research (non-operational) as well.

The tracking program consists of a number of program modules which perform separate (but related) functions during a tracking operation. These modules facilitate program maintenance, modification, and adaptability to any operational or nonoperational sequence.

The majority of input parameters (i.e., injection conditions, physical constants) and all intramodule information are stored on a magnetic tape (reset tape). The reset tape is brought into a common area of core at the beginning of a sequence of modules and is rewritten when the sequence terminates. The reset tape is designed to provide the user with many options, allowing the program to be used for both real-time and nonreal-time applications. The principal program modules are described in the following paragraphs.

Ephemeris Generation Program Module (KEPHFUN)

This module produces listings that describe orbital characteristics for a specified time period and at specified time intervals. Both a condensed online format and a detailed offline format are allowed. The condensed format, which produces one line of output for every time point, contains: time, spherical conditions, height, longitude, latitude; time of apogee, nodal crossing; and entrance to and exit from lunar and solar eclipses. The detailed ephemeris produces Cartesian elements, Kepler elements, altitude, period, node and perigee precession rates,

perigee altitude, and velocities at apogee and perigee in addition to the information produced on the condensed ephemeris. The KEPHFUN module, as well as several other program modules, makes extensive use of the trajectory and orbit calculation subroutine (KTRAJ) whieh is described next.

Trajectory and Orbit Subroutine (KTRAJ)

The trajectory caleulations required by the DDI tracking program are performed by a subroutine whieh numerieally integrates the Cowell equations of motion and optionally integrates a selected subset of the variational equations. The numerical integration is aeeomplished with the use of the Gauss-Jackson seeond summation method employing sixth differenees. A fourth-order Runge-Kutta method is utilized to start integration. Provisions are made for automatic step-size control to minimize local truneation error and eomputing time. Options for eontrolling preeision and speed are set on the reset tape and allow the user to specify:

- Initial step-size
- Minimum step-size
- Maximum step-size
- Limits for eontrolling local truneation error
- Number of signifieant digits to be retained at eaeh integrated step
- An option to eompute, in only speeified terms, the equations of motion and variational equations during the corrector phase of the integration.

If these options are not speeified, nominal values and proeedures are used.

Initial conditions may be specified in the following eoordinate systems: either equatorial geocentric Cartesian, equatorial geoeentric spherical, Keplerian, or ecliptie geoeentric Cartesian.

The equations of motion inelude the effects of zonal, seetoral, and tesseral harmonics up to fourth order of the earth's potential field. Other differential equation parameters such as the Gaussian eonstant, mean equatorial earth radius, astronomieal unit, elliptieity of the earth, and aeceleration of gravity are also specified on the reset tape.

The effects of atmospheric drag are included in the equations of motion. The atmosphere model can be specified as either ARDC 1959, Lockheed-Jacchia, or Paetzold-Jacchia. For low-altitude satellites, tables of C_D versus mach number and C_D versus altitude may be used.

Perturbing-body information is taken from a magnetic tape (perturbation tape) that contains ephemerides for as many as 10 celestial bodies.

Powered-flight segments of the trajectory can be considered. The reset tape provides for as many as 9 orbit adjusts which are specified by time, duration, vehicle weight, flow rate, thrust magnitude, pitch relative to the local horizon, and yaw relative to the orbital plane.

Acquisition Prediction Program Module (KACQTABL)

The KACQTABL module generates a table of rise time, durations, and maximum elevation angles for a selected set of tracking stations over a prescribed time interval. This table is used by the station acquisition model to produce the desired acquisitions and command messages that are transmitted to the tracking stations.

Simulation Program Module (KSIM)

This module simulates the generation of raw radar tracking data from SCF tracking stations. The produced data can be used to facilitate the checkout of the data input and orbit determination programs during the preflight phases.

The user may specify the noise sigmas to be applied to the simulated observations. Also, to produce more realistic data, bore-sightings, radar lock-off bits, and occasional outliers are simulated.

Precision Orbit Determination Module (KODM)

Module KODM accepts and processes tracking data to determine the state of the vehicle during any part of the mission. Additionally, KODM can solve for other trajectory parameters such as drag, orbit adjusts, and tracking station biases. The tracking

data is read from a magnetic tape (observation tape) which is produced by the data input and smoothing program, KOMPACT.

The orbit determination procedure is basically one of solving the classical bounded least-squares problem. A linear system of equations is solved to generate differential corrections for estimated values of selected trajectory parameters. The coefficient matrix ($A^T A$) is inverted by the bordering method with inner products computed in extra-precision arithmetic.

To solve for the specified parameters, the program requires partial derivatives of the observations with respect to the parameters. At present, these partials are computed by numerically integrating the variational equations. However, the program and reset tape logic are designed to permit the use of analytic approximations of the partials.

Options specified on the reset tape allow the user to solve for any subset of the following parameters:

- Initial Condition Parameters

  α = Right ascension
  δ = Declination
  β = Flight-path angle
  A = Azimuth of velocity vector
  R = Radius
  V = Velocity
  t = Time of epoch

- Differential Equation Parameters

  C = Ballistic coefficient ($C_D A / 2M$)

- Orbit Adjust Parameters

  T = Thrust magnitude
  P = Pitch, relative to local horizon
  Y = Yaw, relative to orbital plane

  As many as 3 different adjusts may be solved for simultaneously.

a, b, c: Parameters associated with residual thrust due to gas leakage, where the magnitude is given by an expression of the form

$$T = \left(\frac{a}{b + ct} \right)$$

- Station Parameters

  Biases for range, elevation, azimuth, and range-rate observations

  Biases for more than one station may be solved for simultaneously.

The KODM module is so designed that the addition of parameters to be solved for requires only the expressions for the partial derivatives of the observations with respect to the additional parameters. Other parameters which could be added are:

- Initial condition parameters specified in Cartesian or Keplerian coordinates
- Additional geophysical parameters such as earth radius and coefficients in the harmonic terms of the earth's potential
- Station location errors
- Mass ratios of the perturbing bodies.

Station information may be specified on the reset tape for as many as 50 stations. Included parameters are geodetic latitude, longitude, altitudes, biases for range, azimuth, elevation, range-rate, and time and sigmas for the four observation types. The station data record is designed so that other observation types (e.g., Baker-Nunn data) can be accommodated conveniently.

Options of KODM allow the user to specify the following additional parameters:

- A priori estimates of $A^T A$ matrix
- Bound values
- Bound expansion and compression ratios
- Maximum residuals for initial iteration (data editing-iteration zero)
- Maximum sigma allowable for residuals (data editing-subsequent iterations)
- Limits and volume of observational data to be used
- Maximum number of iterations.

Additional options of the orbit determination program allow the user either to utilize the previous $A^T A$ matrix or to ignore the $A^T A$ matrix, and to update epoch to any specified time, revolution, or perigee time. Since the time of epoch may be any prescribed time, data can be fitted forwards and backwards. Another module of the tracking system allows the user to update the normal matrix and the covariance matrix $(A^T A)^{-1}$ to an arbitrary time.

An additional option of the program permits a compacted set of observations to be used from the reset tape rather than from the observation tape. The compacted data set comprises smoothed points produced by the data input and smoothing program.

Data Input and Smoothing Program Module (KOMPACT)

Functions of the data input module KOMPACT are:

- Reading and editing radar data from SCF tracking stations in the form of paper tape or magnetic tape (transfer tape). Editing is performed by an orbital fit which is similar to a six-parameter initial condition fit with KODM. Radar residuals exceeding a computed value (based on the current RMS, station sigma, and number of prescribed sigmas allowable) cause rejection of the measurements.
- Generating a compacted set of data points that produces zero-residuals in the data fit, and storing them on the reset tape for optional use by KODM
- Optionally, generating a self-starting vector from radar data. A Herrick-Gibbs method is used if range, azimuth, and elevation observations are available. A modified Laplacian method is employed if only azimuth and elevation are available.
- Processing SPACETRACK station data on punched cards or paper tape. (Several additional card formats may also be accepted by the program.)
- Producing a magnetic observation tape for the KODM module. Data is automatically merged and sorted in time sequence to facilitate orbit determination calculations.

In a real-time application, the editing program can operate with little or no human intervention; however, maximum flexibility is provided by allowing some of the editing procedures to be controlled via typewriter input messages.

SYSTEM PROGRAM LIBRARY

As part of a combined effort with CDC personnel, DDI contributed the following programs to the library at the USAF Satellite Tracking Center:

- Generalized output system for editing and preparing reports on a wide variety of output equipment
- Mathematical subroutines, including trignometrical functions, logarithm and exponential functions, square roots, matrix inversions, and the solution of simultaneous equations
- Debugging routines, consisting of core dumps in binary, octal, and floating decimal format.

TACTICAL WARFARE SYSTEMS

Data Dynamics is continuing to provide scientific and analytical support to the Tactical Air Warfare Center at Eglin AFB. An on-site staff is working on a series of current problems confronting the Air Force in the conduct of effective tactical air warfare. Included are such subjects as command and control, weapon assignment, analysis of comparative effectiveness of alternative weapon systems, navigation, reconnaissance, logistics, and basing. The data being analyzed is derived from field exercises, war games, studies, and current experience from Vietnam.

To further supplement these analyses, DDI is designing collection and data processing systems for handling existing and future field test data.

This continuing association has provided DDI with experience in:

- Command and control, analysis, and requirements development
- Development of control functions and operational procedures
- Support of major tests and evaluations
- Operational analysis specifically related to the complex subject of tactical air warfare.

COMMAND AND CONTROL ANALYSIS AND DESIGN

Data Dynamics is presently under contract to provide scientific support to USSTRICOM at MacDill Air Force Base in the development of a command and control system. We are producing a functional analysis of this command's command and control processes, procedures, and requirements, and relating these functions to the design of the 492-L system. This requires study of military command and management processes and the development of organizational procedures and semi-automatic aids for command and control functions.

Also, DDI is developing for the Tactical Air Warfare Center a computer simulation model for exercising and testing tactical air command and control systems. The scope of the effort includes development of performance parameters, system descriptions, evaluation factors, and computer language and models.

STRATEGIC SYSTEMS

Data Dynamics is experienced in performing systems analysis, synthesis, optimization, and interactive analysis to determine potential system performance and the trade-offs inherent in alternative configurations of advanced offensive and defensive weapon systems. Projects in this area have included:

- Analysis and synthesis of ballistic missile defense systems and subsystems
- Antisatellite systems and penetration aids effectiveness analyses
- Electronic countermeasures and effects upon military forces
- Modeling, gaming, and development of military actions, reactions, and interactions involved in predetermining the impact of science and technology on the future posture of forces
- Optimization of space and subspace vehicle launch operations.

ENVIRONMENTAL SCIENCES

The staff of DDI includes scientific personnel with meteorology training and particular experience in numerical weather prediction and analytical methods. Recent contracts have involved building large historical files of meteorological parameters, radiological fallout studies, environmental influences under command control systems, ballistic wind studies, very high level density studies, and radar refraction studies.

Currently, the DDI staff is providing support for the U.S. Navy ASWEPS program. This is largely a computer programming task to fit oceanographic techniques to a large Navy weather service computer system for near real-time daily operations.

COMPUTER SCIENCES

Data Dynamics has extensive experience and capability in the computer sciences with particular emphasis in the areas of real-time processing, communications, operational systems, assemblers, compilers, simulators, and the mathematics of computation. This capability has been developed not only in performance of independent contracts, but also in support of projects utilizing DDI's other technical capabilities.

An example of this activity is the program developed for the Control Data Corporation which completely simulates the IBM 1401 computer using the Control Data 3200. This program relieves the problem of customer reprogramming in the changeover from one computer to another and represents a significant advance in computer simulation technology.